



B05: ETL Overview

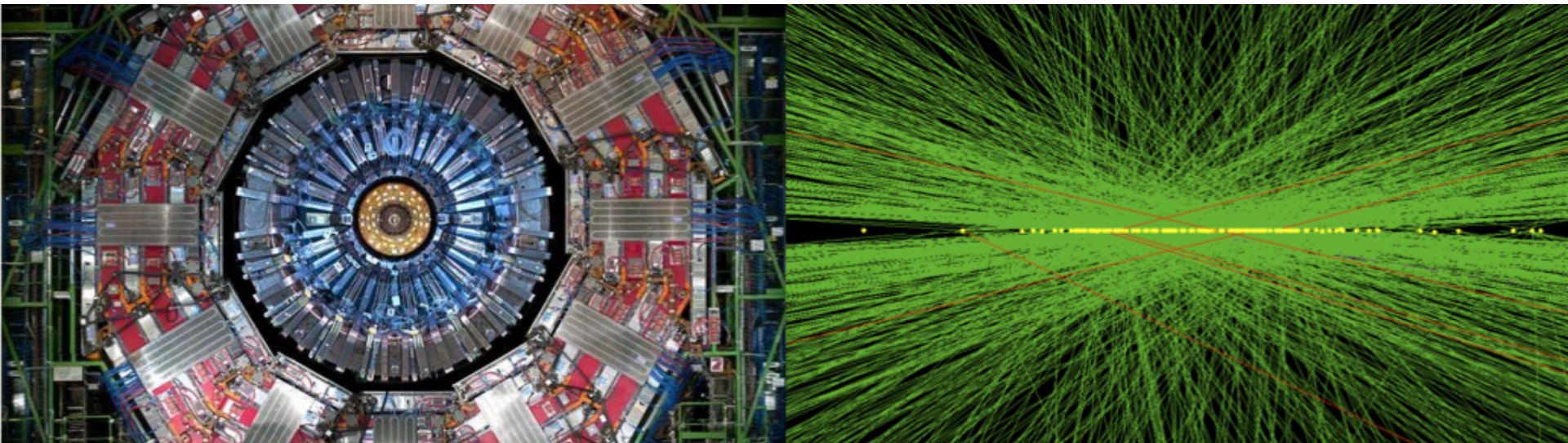
402.8.4

Artur Apresyan

Fermilab

HL-LHC CMS CD-1 Review

23 October 2019



Brief Biographical Introduction

- Associate scientist at Fermilab
- Roles in international MTD :
 - L4: ETL Engineering
- Roles in US-CMS MTD :
 - L3: Endcap Timing Layer
- Development of precision timing detectors
 - DOE ECA award in 2018 to work on precision timing detectors
 - FNAL LDRD in 2017, US-Japan Science Cooperation award in 2019 to work on LGAD sensors R&D
 - Precision timing detector R&D since 2012
- CMS Original Forward Pixel; HCAL operations and reconstruction
- CMS/CDF data analysis: Higgs searches, SUSY and Exotica

Outline

- Conceptual Design
- Scope and deliverables for ETL (402.8.4)
- Cost and Schedule
- Contributing Institutions
- Resource optimization
- ES&H
- QA/QC
- Summary

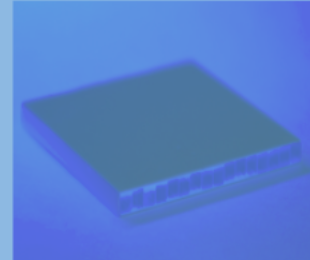
Conceptual Design, Scope and Deliverables

MTD Conceptual Design



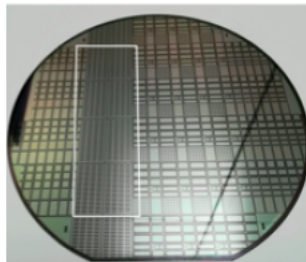
BTL: LYSO bars + SiPM readout:

- TK / ECAL interface: $|\eta| < 1.45$
- Inner radius: 1148 mm (40 mm thick)
- Length: ± 2.6 m along z
- Surface ~ 38 m²; 332k channels
- Fluence at 4 ab⁻¹: 2×10^{14} n_{eq}/cm²



ETL: Si with internal gain (LGAD):

- On the CE nose: $1.6 < |\eta| < 3.0$
- Radius: $315 < R < 1200$ mm
- Position in z: ± 3.0 m (45 mm thick)
- Surface ~ 14 m²; ~ 8.5 M channels
- Fluence at 4 ab⁻¹: up to 2×10^{15} n_{eq}/cm²



MTD provides precision time measurement for MIPs with $\sigma_t = 30\text{-}40$ ps with sufficient radiation tolerance to maintain $\sigma_t < 60$ ps up to 3000/fb.

Design constraints & Performance

- Time resolution per track: 30-40 ps at the start of HL-LHC, < 60 ps up to 3000 fb⁻¹ assuming nominal fluence
- Particle flow reconstruction performance at high PU comparable to Phase-1 CMS.
 - Extend reach for a broad class of new physics searches with long-lived particles
- Achieve radiation tolerance up to $1.7 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ at $|\eta| = 3.0$
 - Fluence is less than $1 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ for 80% of the ETL surface area
- Low occupancy to ensure small probability of double hits, needed for unambiguous time assignment
- The ETL detector designed to be accessible for maintenance
 - Maintain an independent cold volume which is isolated and operated separately from the HGCal
- MIP Timing Layer HL-LHC Design Specifications tracked in:
 - <https://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=13536>

ETL 402.8.4 WBS Structure

- ETL project subdivided into 3 tasks:

- 402.8.4.2: Frontend ASIC

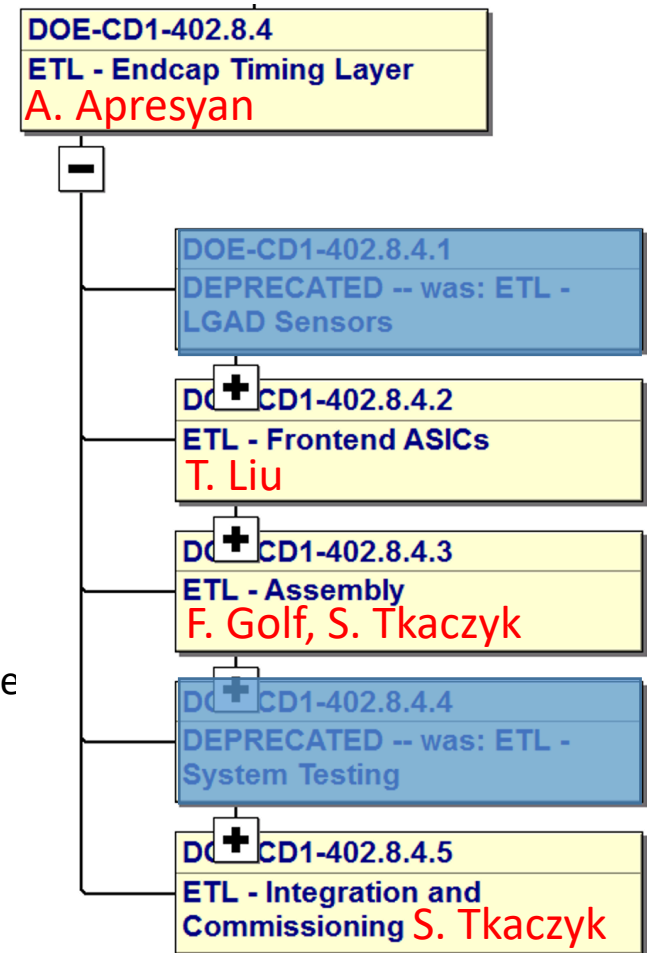
- Design, test, and procure 50% of ASICs
 - Ted Liu → separate talk

- 402.8.4.3: Module assembly

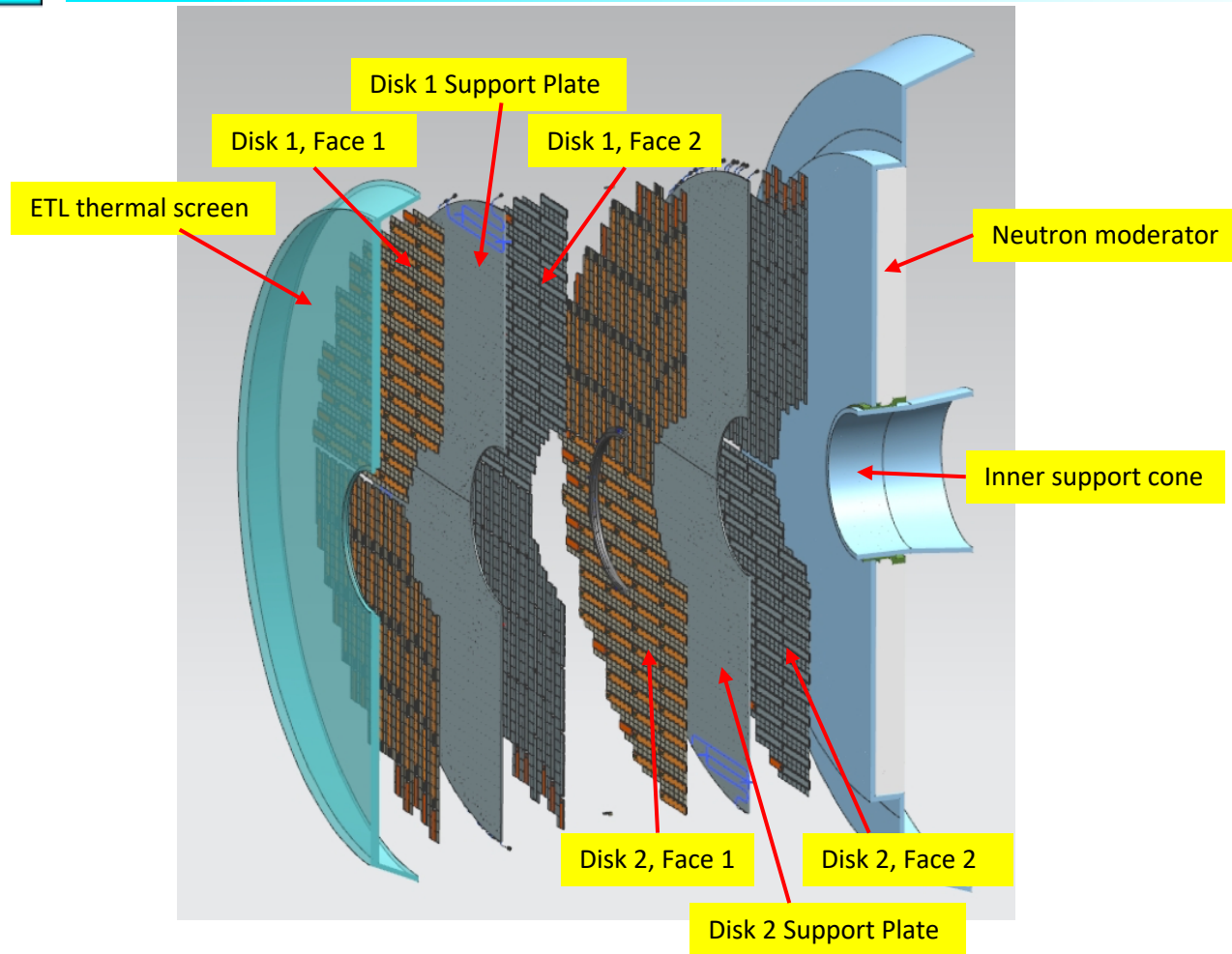
- Assemble, test, and deliver 50% of ETL modules
 - Frank Golf → separate talk

- 402.8.4.5: Integration and commissioning

- Participation in I&C activity at CERN, jointly with other ETL collaborators
 - Slawek Tkaczyk



ETL Overview

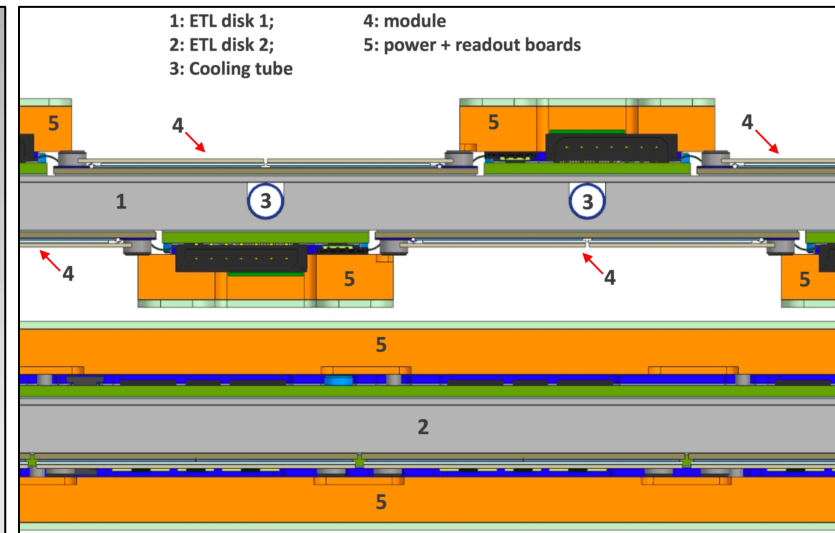
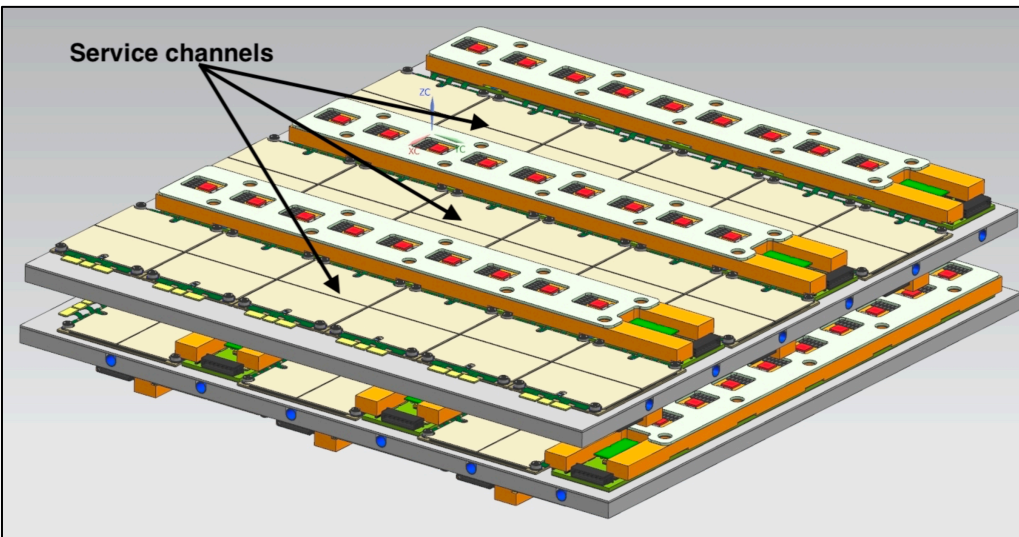


- Placed on the nose of HGCal ($1.6 < |\eta| < 3.0$)
 - Total silicon surface area of $\sim 14 \text{ m}^2$ for the two Z-sides.
- Ensure that there are 2 hits for the majority of tracks

ETL Structure

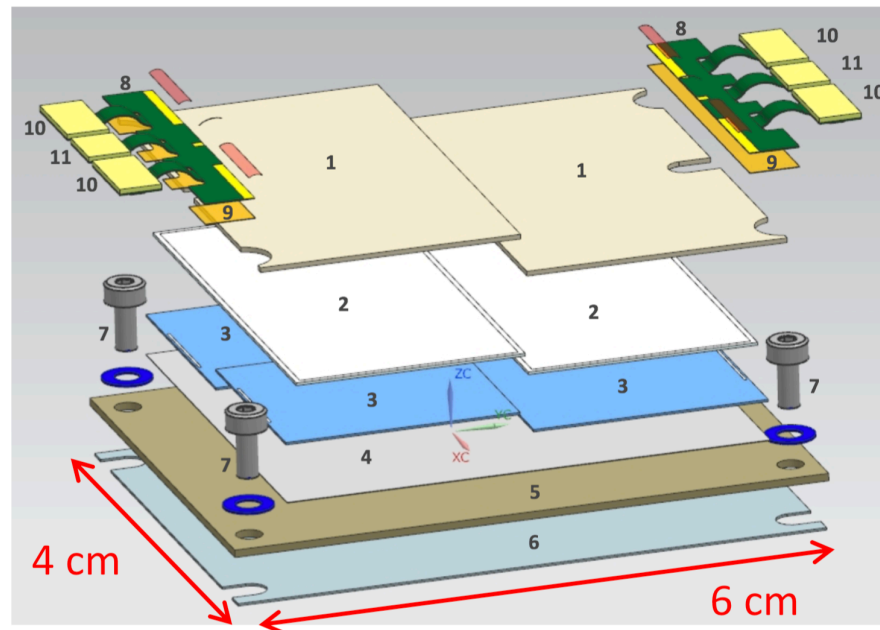
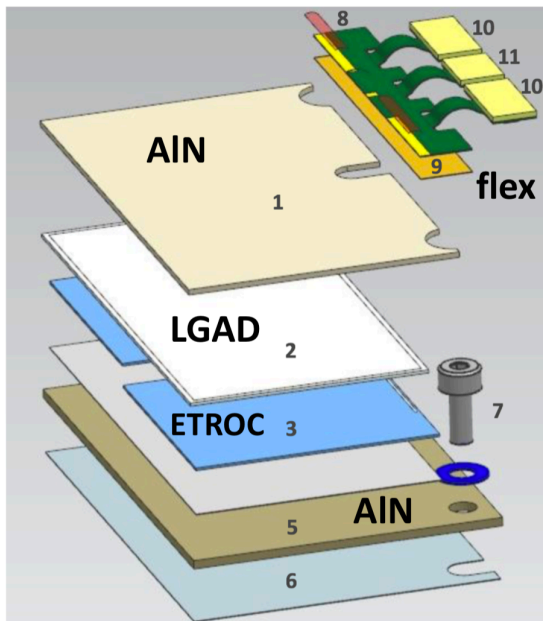
■ General structure

- Modules mounted on the cooling support structure
- Flexible circuit connects readout chips to power & readout PCB
- Dual-phase CO₂ cooling is used to remove the heat



Modules

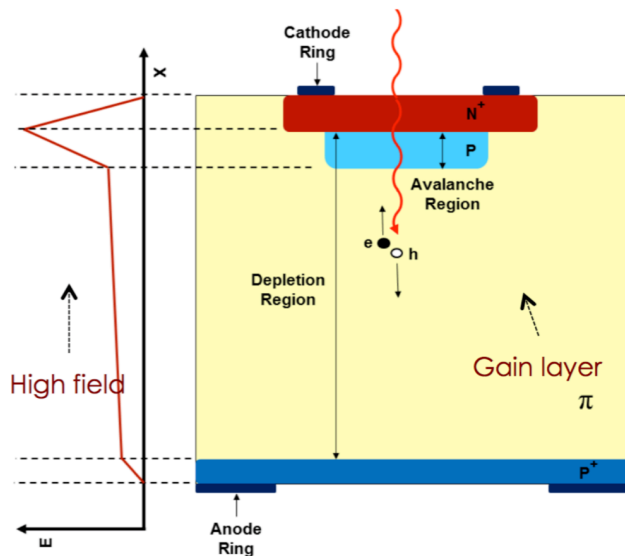
- The ETL modules are built from sub-assemblies containing sensors that are bump bonded to two readout chips each
 - Flex circuits laminated to edge of the AlN substrate provide electrical connections
 - A second AlN plate is fixed atop this structure to protect the sensors
- US-CMS will assemble and deliver 50% of ETL modules
- *More details in Frank Golf's talk*



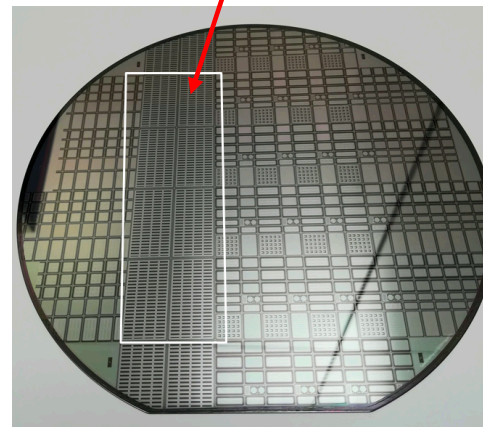
- 1: AlN module cover
- 2: LGAD sensor
- 3: ETROC
- 4: Mounting film
- 5: AlN carrier
- 6: Mounting film
- 7: Mounting screw
- 8: Front-end hybrid
- 9: Adhesive film
- 10: Readout connector
- 11: High voltage connector

LGAD sensors

- Silicon sensors with specially doped thin region with high electric field → produces avalanche signal with 10-30 gain
 - Each sensor contains a 16×32 array of pads of size $1.3 \times 1.3 \text{ mm}^2$
- Demonstrated time resolution of LGADs: $\sim 30 \text{ ps}$ up to $1 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, and about 40 psec up to $2 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$
 - LGAD sensors are not in the US project scope
- Large community:
 - RD50 collaboration, several manufacturers: CNM, FBK, Hamamatsu
 - CMS/ATLAS joint production runs with all three companies in 2018

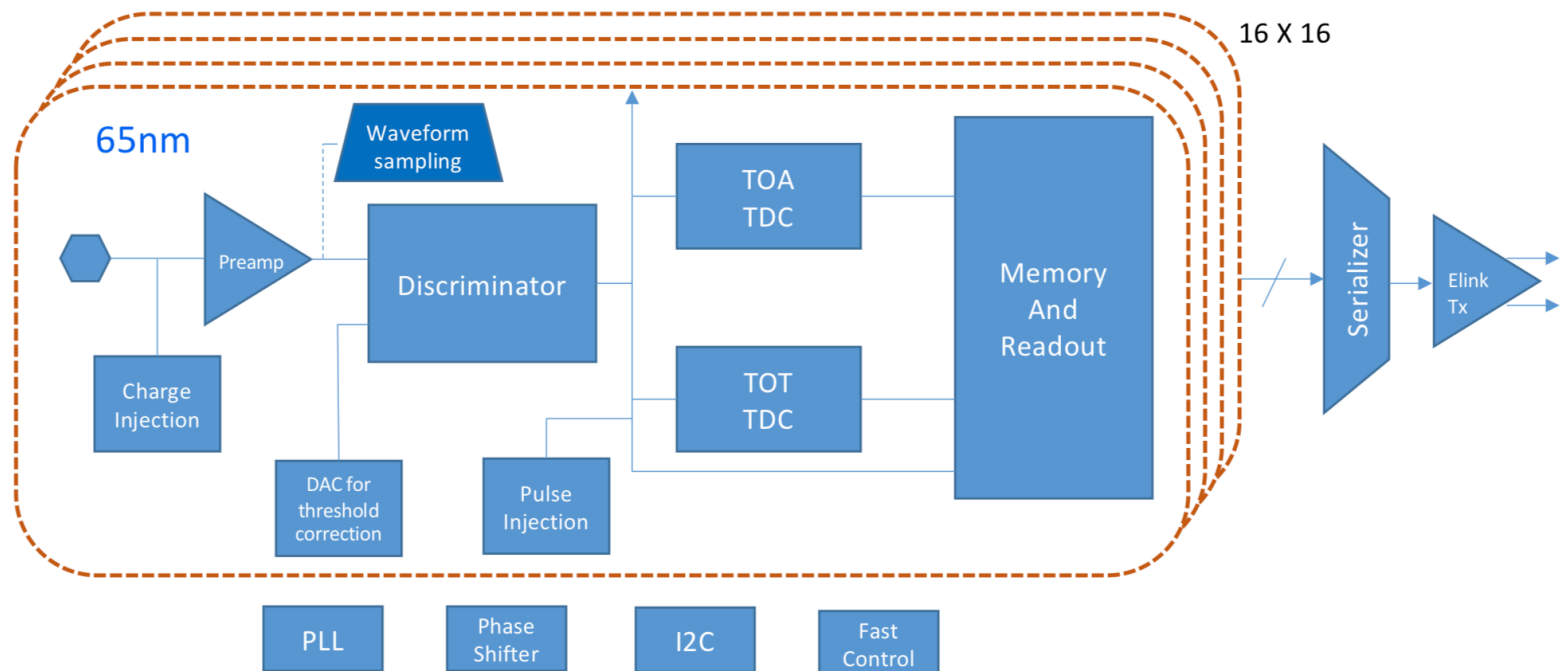


CMS-designed sensors



FBK wafer with CMS- and ATLAS- sensors

- ETROC is bump-bonded to LGAD sensor
 - 256 pixel matrix (16×16), each 1.3×1.3 mm²
 - 65 nm technology for radiation hardness and low power
 - ASIC contribution to time resolution < 40ps
- US-CMS will design, deliver, and test ETROCs
- *More details in Ted Liu's talk*



Integration & Commissioning

- Components will be received at the Endcap Calorimeter Assembly Facility (ECAAF) at CERN.
 - Test modules and service hybrids upon reception.
 - Module and service hybrids mounted on wedges using screws.
 - Power and data services installed and routed on wedges.
 - Test at room temperature to verify electrical connectivity.
 - Connect to CO₂, power services, and a DAQ test stand and perform longer-term, cold-temperature test of integrated wedge.
- The ETL schedule allows for flexibility in the integration.
 - Modules integrated onto disks that can either be installed on the surface or underground

R&D achieved and remaining

■ ETROC

- Single- channel analog front-end designed and tested
- 4x4 channel ASIC submitted in August 2019
- 16x16 chip design specification developed and documented
- Details in T. Liu's talk

■ Module Assembly

- Module design and assembly procedure well defined.
- R&D is ongoing to: validate the module design, and develop the module assembly procedure, QA/QC
- Details in F. Golf's talk

■ Integration & Commissioning

- Integration of ETL services with the full CMS defined, design completed
- Installation procedure to be worked out in detail.

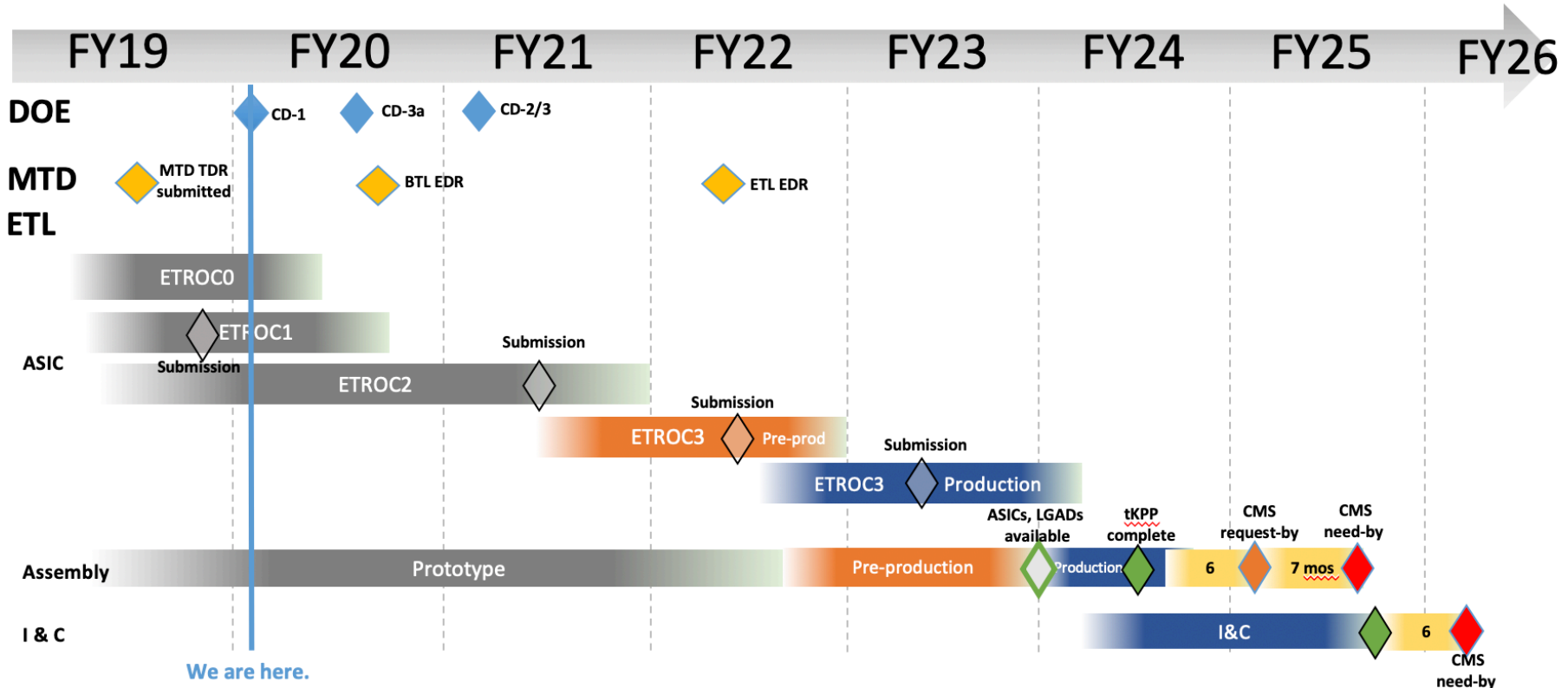
Interfaces

- Interfaces and dependencies documented in cms-doc-13536
- ETROC interfaces:
 - LGAD dimensions and pixel sizes, ETROC pinout, matching specs with service hybrid
 - Data format, power requirements, cooling specifications
- Module interfaces:
 - Specification of modules sizes and types, flex connector locations and types
 - ETROC+LGAD bump-bonding specification, yield
 - Module cooling and connectivity to service hybrid
- Overall detector interfaces
 - System Dimensional Envelopes: ETL detectors must conform to the MTD detector geometry summary document
 - CO2 cooling: provided by the CMS common cooling plants
 - Detector Safety System: monitoring, control (DCS) and interlocks (DSS) must conform and interface to the CMS DCS and DSS systems.

Schedule and cost

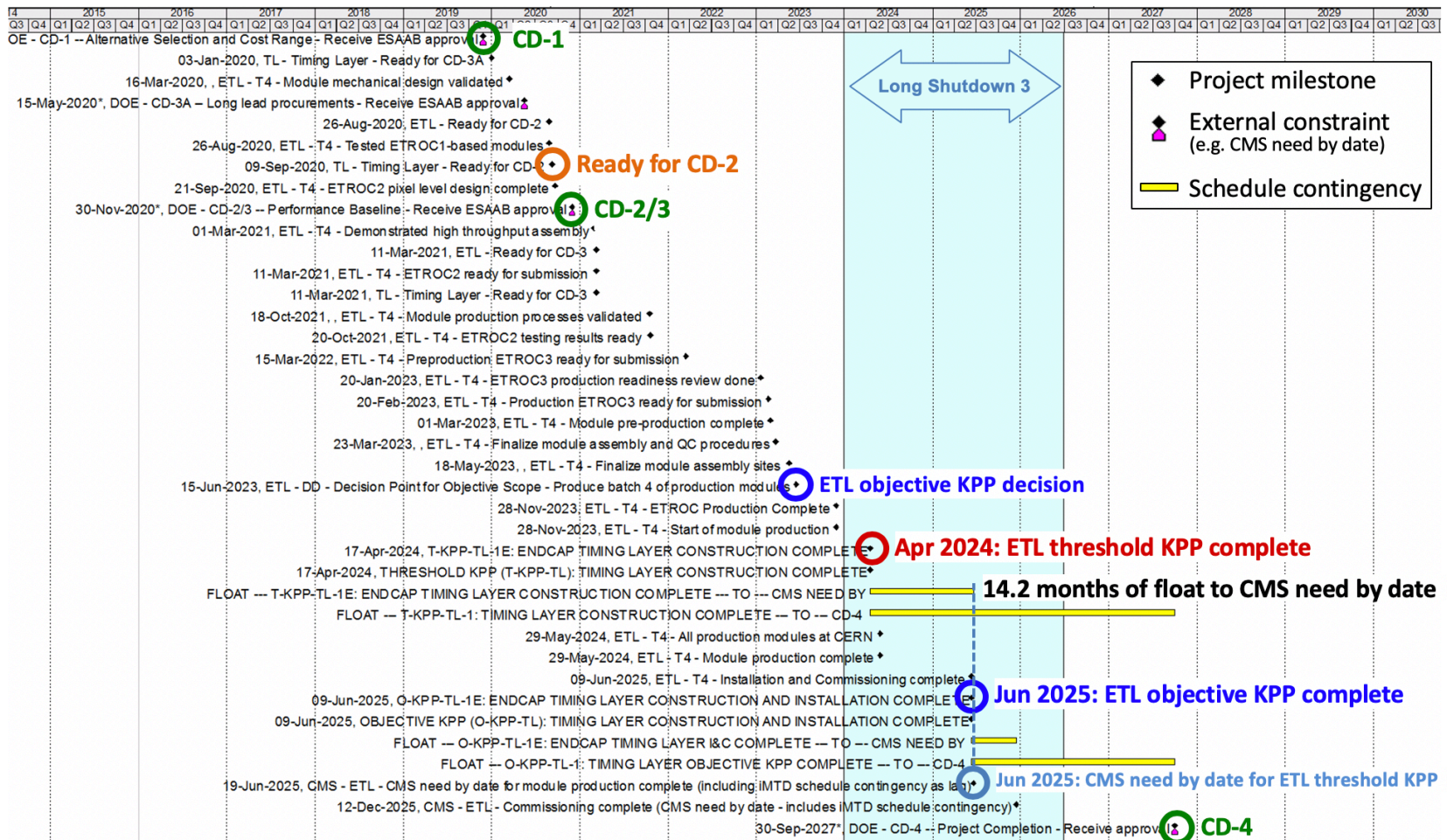
Schedule Overview

- ETL schedule driven by ETROC availability
- Assembly schedule driven by availability of bump-bonded LGAD+ETROC sub-assemblies.
- Detailed resource loaded schedule is available in P6, Scrutiny in context of TDR review, in preparation for LHCC



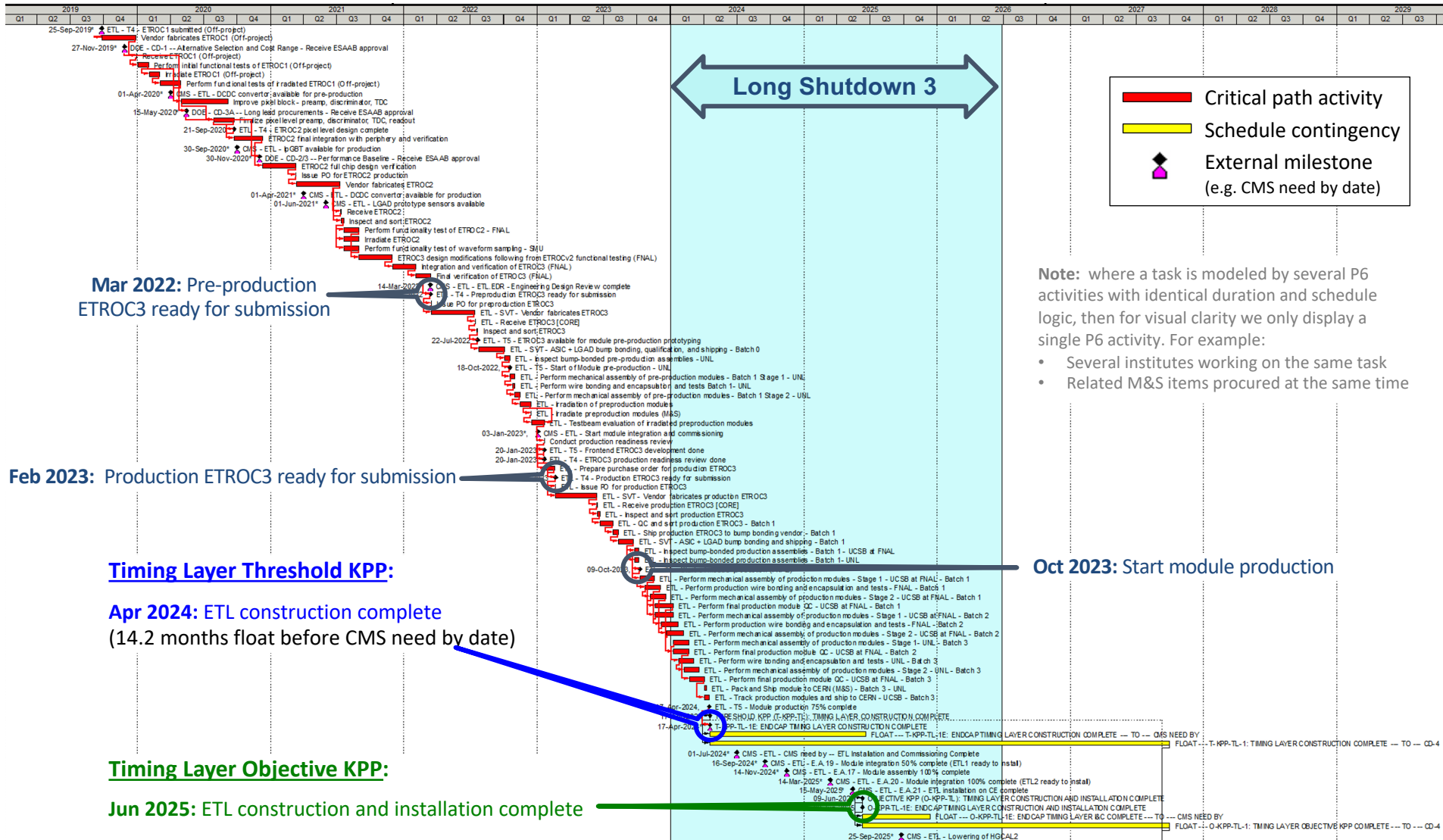
Milestones for 402.8.4

- Major milestones for end preproduction, production and end of the project defined. cms-doc-13321
 - Finer grained milestones are listed in P6



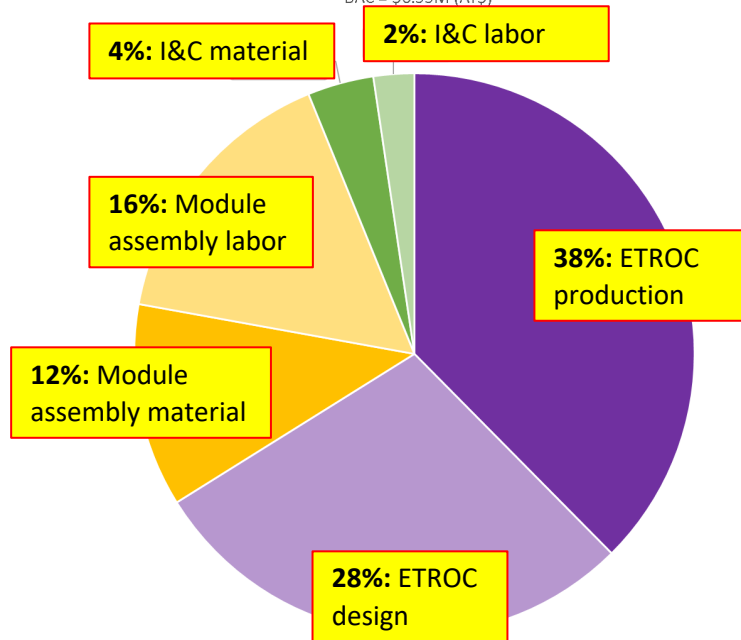
Critical Path items for 402.8.4

Further details in F. Chlebana's talk

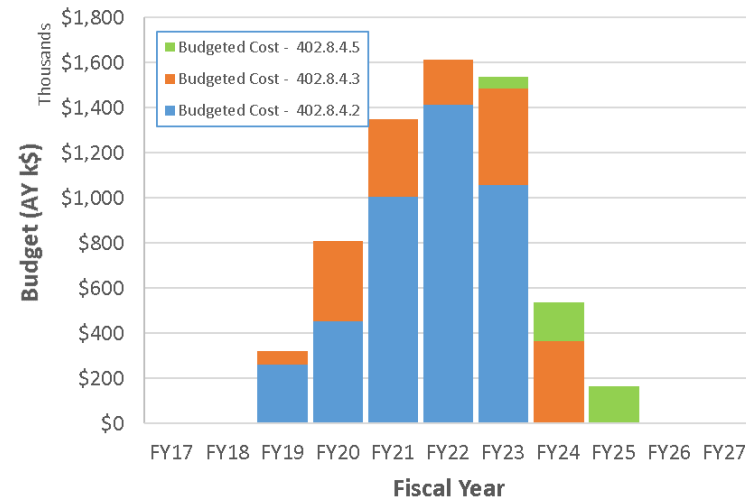


Cost Estimate

402.8.4-TL-WBS L4 Base Budget Breakdown (DOE)
BAC = \$6.33M (AY\$)



402.8.4-TL-Base Budget Profile (DOE)-WBS L4 Subprojects
BAC = \$6.33M (AY\$)



- ETROC production, and module assembly labor and M&S are the main cost drivers
- Cost drivers for I&C:
 - Purchase of environmental chamber and electronics for system tests
 - COLA for students and postdocs; salaries for engineer/technician for I&C

ETL risks

WBS / Ops Lab Activity : 402.8.4 ETL - Endcap Timing Layer (10)						
Risk Rank : 3 (High) (1)						
RT-402-8-01-D	ETL - Additional FE ASIC prototype cycle is required	40 %	500 -- 600 -- 700 k\$	4 -- 5 -- 6 months	240	2.0
Risk Rank : 2 (Medium) (5)						
RT-402-8-03-D	ETL - FE ASIC does not meet specs - needs another pre-prod run	10 %	874 -- 930 -- 986 k\$	6 -- 7.5 -- 9 months	93	0.8
RT-402-8-55-D	ETL - Schedule delay in submitting ETROC2	30 %	55 -- 110 -- 165 k\$	2 -- 4 -- 6 months	33	1.2
RT-402-8-02-D	ETL - ETL module facility unavailable	50 %	20 k\$	2 months	10	1.0
RT-402-8-10-D	ETL - Sensor quality problem during production	15 %	28 -- 52 -- 109 k\$	2 -- 3 -- 6 months	9	0.6
RO-402-8-01-D	ETL - Use AltiROC	10 %	-720 k\$	-8 months	-72	-0.8
Risk Rank : 1 (Low) (4)						
RT-402-8-54-D	ETL - Schedule delay in submitting ETROC3	20 %	27.5 -- 55 -- 82.5 k\$	1 -- 2 -- 3 months	11	0.4
RT-402-8-53-D	ETL - Integration facility at CERN runs out of components	25 %	21 k\$	3 months	5	0.8
RT-402-8-31-D	ETL - Storage-related degradation of LGADs	10 %	18 k\$	3 months	2	0.3
RT-402-8-51-D	ETL - Problem with vendor provision of module components	5 %	0 -- 15 -- 30 k\$	1 -- 2 -- 3 months	1	0.1

- Project governed by Fermilab Risk Management plan.
- Risk workshop with external reviewers conducted.
- Dominated by risks related to ETROC, details in Ted's talk
- Documented in cms-doc-13480

Contributing Institutions and Resource Optimization

Contributing Institutions

- ETROC effort led by FNAL team in collaboration with SMU
 - Years of experience in designing ASICs for HEP experiments
- Modules assembly and system testing will be done at *FNAL & UNL*
 - Extensive recent experience in design/assembly of silicon detectors for HEP
 - UNL and FNAL will serve as assembly sites. UCSB+BU will provide additional labor.
 - SiDet and Test Beam facility at Fermilab for prototyping, assembly and testing
- Modules bump-bonding quality control at *U of Kansas*:
 - Extensive recent experience in QA sensor testing for Phase 1 pixel detector
- Integration and Commissioning at CERN
 - Work performed largely by students and postdocs

Resource Optimization

- We follow value engineering in organization of the project and optimal use of resources (cms-doc-13475).
- Reuse of elements from other phase 2 projects
 - Common IPs through IpGBT and RD53 developments
 - Reuse of the OT power supply units, bump-bonding studies for MAPSA
 - Use of standard IMEC agreements with TSMC for discounts in ASIC production
 - Reuse the CO₂ plant at FNAL for prototype testing
- Shared costs in labor and discounts in prototyping stage LGAD sensor R&D in collaboration with ATLAS and iCMS
- Construction model:
 - Module construction will be shared among two sites in US, with shared prototyping efforts

- All ES&H aspects of the HL LHC CMS Detector Upgrade Project will be handled in accordance with the Fermilab Integrated Safety Management approach, and the rules and procedures laid out in the Fermilab ES&H Manual (FESHM)
 - The current construction plan involves no materials of identified environmental risk: cooling plant is based on CO₂ rather than Freon
- Detector will use high voltage (~ 600 V) and will be operated in a refrigerated mode (-30°C), similar to OT and HGCaI
 - Standard operational procedures will be developed and documented to allow safe operation
- R&D and some production testing will involve the use of gamma, neutron, and proton radiation.
 - These tests will be performed at commonly-used radiation facilities and will follow the standard operational procedures defined at each facility
- Documented incms-doc-13394

Quality Assurance and Quality Control

- Quality Assurance & Control plan documented in cms-doc-13536
- Quality Assurance : Prevention of Issues
 - Prior to the production of ETL modules, several prototype rounds are planned to identify potential problems and minimize the impact to cost or schedule:
 - A series of prototypes, both mechanical dummy and functional
 - Checkpoints/reviews in early production for prototypes to identify issues
 - Fixed procedures for construction, automation
 - Testing procedures: test-beams, integration testbeds, radiation testing including operation of systems under irradiation, thermal cycling tests
 - System tests will be performed on assembled modules to assure quality
- Quality control : Identification of issues
 - The procedure for module assembly and quality control will be developed during prototyping period.
 - module components will be tested prior to the final assembly during production
 - Use databases to track all components through the assembly and testing processes
 - Verify that only good quality components (sensors, power and readout boards, and ASICs) are assembled into modules

Summary

- We have made significant progress in all areas since June 18
 - ETL design is well defined
 - Prototype sensors from FBK and HPK look great, demonstrated radiation tolerance for HL-LHC
 - ETROC0 prototype testing looks great, ETROC1 submitted Aug 2019
 - Fast progress in the module assembly and QA development
- Cost, schedule and risks are understood and documented
- A strong team of contributing institutions in the US and internationally
 - Significant experience of designing, building, and testing silicon detectors for HEP experiments
- Conceptual design is complete and well on the way to baselining.